THE LAMELLAR STRUCTURE AND BIREFRINGENCE OF PLATE GLASS

BY SIR C. V. RAMAN

(From the Raman Research Institute, Bangalore)

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1. INTRODUCTION

COMMON sheet or plate glass is manufactured by passing molten glass while in a plastic state between moving rollers and possesses a lamellar structure which owes its origin to this dynamic procedure of shaping the material. The structure becomes visible when a strip of the plate glass is viewed edgewise through a magnifier, using light which has traversed the strip in a direction parallel to its surfaces. The entire thickness of the strip is seen to be made up of a great number of distinct laminæ parallel to each other and to the surfaces of the strip. That the lamellar structure is associated with a characteristic type of birefringence becomes evident when the plate is viewed in the same manner when held between crossed polaroids. A strong restoration of light is then observed except when the surfaces of the strip are parallel to the vibration direction of either the polariser or the analyser. The individual laminæ differ in the strength of their birefringence as indicated by the intensity and colour of the restoration of light which they produce in these circumstances. The variation in birefringence in the successive laminæ may be exhibited by superposing a quartz wedge lengthwise over the edge of the strip. Photographs of these effects were reproduced with a recent paper in these *Proceedings* to illustrate the thesis that amorphous solids may exhibit an intrinsic or structural birefringence arising from the circumstances of their formation and distinct in its nature from the well-known double refraction produced by stress (Raman, 1950).

We return to the subject in the present communication mainly because better technique has since made it possible to portray the lamellar structure of plate glass and the birefringence associated with it in a more satisfactory manner. By using glass strips with edges ground flat and polished, and employing a higher magnification with the illumination so adjusted as to secure optimum visibility of the structure, the earlier photographs have been greatly improved upon. This will be evident on a comparison of Figs. 12 and 13, 14 and 15, 16 and 17, in Plate XIII of the previous paper with the corresponding Figs. 1 and 2, 3 and 4, 5 and 6 in Plate XVIII accompanying the present communication. The number of distinct laminæ visible is now much larger; for instance, some thirty laminæ are visible in a 1/16″ glass plate (Fig. 5), while in a ¼″ glass plate (Fig. 1) at least a hundred may be counted. Fig. 2 exhibits at its extreme left a small part of the edge of a strip of a ¼″ plate not covered by the quartz wedge; its continuation towards the right on which the wedge fringes appear superposed exhibits the variation of the birefringence over the entire thickness. The photograph shows that the birefringence is noticeably discontinuous as between the successive laminæ. Figs. 4 and 6 in Plate XVIII similarly illustrate the effect of superposing a quartz wedge on the birefringence patterns of 1/8″ and 1/16″ plate glass. The same without such superposition are reproduced as Figs. 3 and 5 respectively in the Plate.

Careful examination of a six-inch strip of ¼″ plate glass one inch wide showed no noticeable change even in respect of the finer details of its lamellar structure over its entire length or as between the two sides of the strip. Considering the observed facts in their entirety, *viz*., the great number of the individual laminæ, their sharpness, their remarkable parallelism and uniformity, as well as their association with a birefringence which varies in a discontinuous manner as between adjacent laminæ, we are led to the conclusion that they represent essentially a stratification in the physical structure of the medium resulting from the circumstances of its formation, as already indicated. We may, in fact, not inaptly compare the lamellar structure of plate glass with the sets of parallel slip-planes well known to be present in crystalline solids which have been subjected to plastic deformation.

2. The Visibility of the Stratifications

The conditions under which the lamellar structure and the associated birefringence are most clearly visible are related to the optical effects produced by the stratifications in the medium when light traverses it. As already indicated, the observation of the laminæ requires that the plate should be viewed edgewise and that the incident light beam should traverse it in a direction parallel to its surfaces. To secure this condition, it is obviously necessary to restrict the angular extension of the source of light. Indeed, the structure is completely invisible when the plate is viewed edgewise against an extended source of light, *e.g*., an open window. It is also invisible when light arising from a source of restricted area traverses the plate in a direction inclined at more than a few degrees of arc to the plane of the laminations. The reason for these facts becomes apparent when a narrow illuminated slit is viewed from a distance through the edge of the plate held parallel to it. The slit is then seen spread out into a diffraction pattern. This is most conspicuous when the direction of observation is exactly parallel to the surfaces of the plate. It undergoes various changes and ultimately disappears, leaving only the undeviated image of the slit, as the plate is tilted and the light traverses it in a direction inclined to its surfaces when such inclination exceeds a few degrees of arc. We conclude from these observations that the lamellar strucure is visible when it is capable of producing observable diffraction effects and that it ceases to be visible when such effects do not arise.

It is not to be understood from the foregoing that a narrow slit is the most suitable source of illumination for observing the lamellar structure. Indeed, with such a source, the structure appears overlaid by numerous fine streaks displaying colours, evidently due to interference. To suppress these, the angular width of the source should be increased, but not to such an extent as to obliterate the details of the structure. Actually, there is an optimum value for the angular extension of the light-source in a direction transverse to the stratifications which enables them to be seen most clearly. In these circumstances, the structure reveals itself as a series of dark lines of varying width and intensity traversing a bright field, provided the plate is held symmetrically with respect to the angular extension of the source.

It is worthy of remark that the birefringence may be observed even when the lamellar structure is invisible by reason of too great an angular extension of the light-source. It then manifests itself as a restoration of light in which the differences between adjacent laminæ are obliterated. Even so, the birefringence is seen to vary over the thickness of the plate. Two dark lines running parallel to each other with bright strips on either side are seen on the edge of the plate, except near its free ends where they curve round to join the corners. These dark lines evidently represent the neutral lines where there is no birefringence separating regions in which the birefringence is of opposite signs. In general, they appear symmetrically placed with reference to the edges of the strip and divide its area approximately in the ratio 1 : 3 : 1, but there are also exceptions, as for instance, the $\frac{1}{8}''$ plate whose structure is represented in Figs. 3 and 4 in Plate XVIII.

3. The Diffraction Phenomena

We proceed to consider the diffraction effects alluded to above which are observed when a fine illuminated slit is viewed edgewise through a plate held parallel to it. These effects depend on the intrinsic character of the stratifications, but they are also influenced by the circumstances of observation, *viz.*, the depth of the medium through which the slit is viewed, the inclination of the incident light rays to the plane of the stratifications and also by the width of the aperture of observation which determines the number of stratified layers effectively taking part. A study of the influence of these factors reveals various similarities between the present case and the diffraction effects arising when light traverses a medium containing a stationary pattern of ultrasonic waves. The explanation of the latter effects (Raman and Nath, 1935 and 1936) enables us more readily to understand the phenomena observed in the present case, though there are also important differences to be noted.

The depth of the stratified medium which the light has to traverse can be varied within wide limits by altering the width of the strip of glass cut and prepared for the observations. When a narrow illuminated slit is viewed in a direction parallel to the surfaces of the strip, it is found that the greater the depth of the medium, the larger is the fraction of the incident energy which is thrown into the diffraction pattern. This appears extending symmetrically on either side of the slit. When the depth of the medium is sufficiently large, the whole of the incident light is diffracted and the slit itself ceases to be visible. Simultaneously, the diffraction pattern widens out on either side, the direction of maximum intensity remaining at its centre.

The character of the effects observed is notably altered when the surfaces of the plate are inclined to the direction of the illuminated slit. If the depth of the medium is not altogether too small, the effect of such inclination is to divide the pattern into two distinct parts, one of which remains at the centre and the other moves away to one side of it. We may describe these as the *transmission* and *reflection* patterns respectively, these words being indicative of their origins as well as of their geometric positions. As their separation increases, the reflection pattern diminishes in intensity and ultimately disappears, while the transmission pattern contracts by gaining intensity at the centre and losing it at the margins, until finally only the undeviated image of the slit is seen. The separation of the diffraction pattern into two distinct parts as described above is not so evident if the depth of the medium is small. The effect of inclining the plate in such a case is to cause the diffraction pattern at first to expand laterally in an unsymmetrical fashion and then to contract once again and finally to disappear.

Even when the source is of white light, the diffraction pattern exhibits a visible structure; with monochromatic light, it appears resolved into a crowd of discrete lines. The latter observation may, at first sight, seem to be surprising in view of the fact that the stratifications in the medium are very far indeed from constituting a regular diffraction grating. Actually, however, the result observed is that which is theoretically to be expected. For, while the diffraction of light by the individual stratifications determines the angular *extension* of the pattern, its *structure* is determined by the interference of the effects of all the stratifications falling within the aperture of observation. A regular stratification would give rise to a relatively small number of intense maxima of illumination appearing as lines in the diffraction pattern. On the other hand, an irregular stratification woluld give rise to a much larger number of maxima but of correspondingly diminished intensity. But their sharpness would, in either case, be determined by the total aperture of observation and hence would be the same in both cases. The case is analogous to the diffraction of light by a cloud of small particles distributed irregularly over the area of an aperture; these are observed to give rise to a great many *sharply defined* images of the light-source in the field of view (Ramachandran, 1943).

4. Observations with Polarised Light

As we are here concerned with the optical behaviour of a stratified *birefringent* medium, the question naturally arises whether the diffraction effects arising when it is traversed by light would depend on the state of polarisation of the latter at entry. It is evident from the observed facts that the retardation of phase produced by the plate differs for vibrations respectively parallel and perpendicular to the stratifications and that such difference is not the same for all of them. Hence the rays emerging from the glass would differ from each other in phase to an extent depending on the state of polarisation of the incident light. In these circumstances, we may expect the diffraction pattern to be noticeably different for the two components of the light vector.

That the stratifications are far from being perfectly periodic and that in consequence the diffraction pattern does not possess a simple structure makes an experimental test of the theoretical conclusion stated above not so easy as may seem at first sight. Careful studies using a monochromatic light-source would be needed to reveal the expected effect in all its detail. Some preliminary observations which have been made with a white light-source however indicate that an effect of the nature indicated does exist. For this purpose, a slip of glass one millimetre thick was prepared and polished so as to have reasonably flat and parallel faces. It was placed between a pair of polaroids and an illuminated slit was viewed through the combination. When the polaroids were in the crossed position and the stratifications in the glass were inclined at 45° to their vibration directions.

the diffraction pattern continued to be visible as the result of the birefringence of the glass, though rather faintly. One of the polaroids was then rotated a little with respect to the other. It was then observed that the pattern became brighter but with a very noticeable change in its structure, some parts gaining intensity much more than others.

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Summary

Using carefully prepared material with adequate magnification under conditions securing the optimum visibility, photographs exhibiting the lamellar structure of plate glass and the associated birefringence have been secured which exhibit far more detail than previously. The visibility of the structure is closely related to the diffraction phenomena to which it gives rise. The latter are described and discussed in detail.

References

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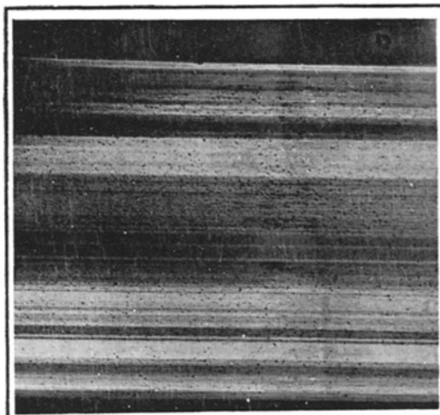

Fig. 1

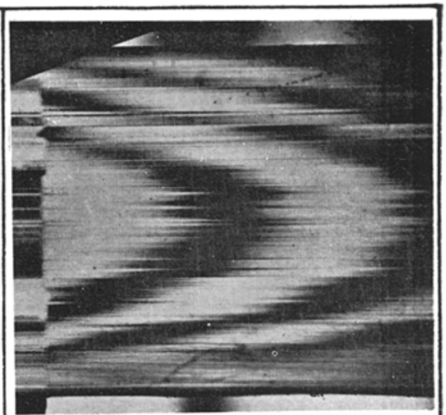

Fig. 2

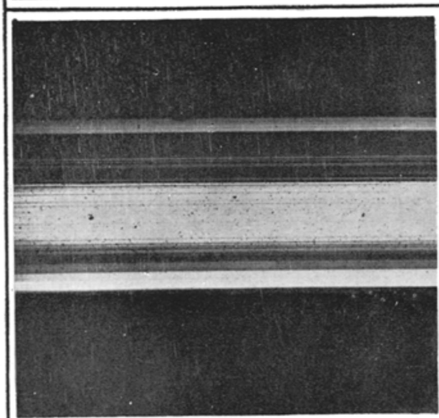

Fig. 3

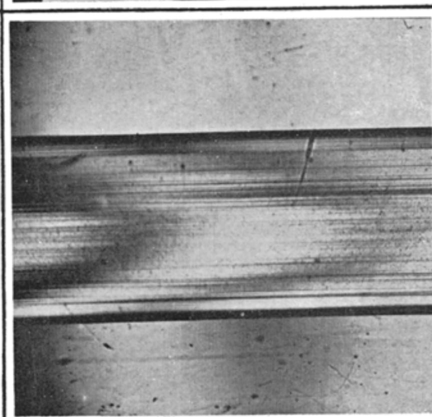

Fig. 4

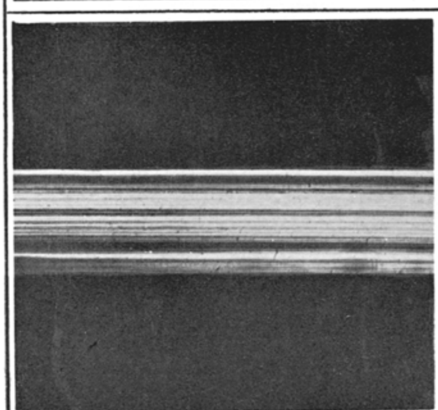

Fig. 5

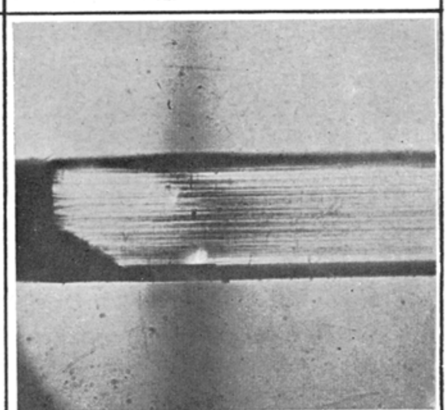

Fig. 6